IDENTIFICATION, PRIORITIZATION, AND MITIGATION – A THREE STEP PROCESS FOR STORMWATER QUALITY MANAGEMENT

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ABSTRACT

Development of effective plans for stormwater quality management to mitigate the degradation of freshwater quality in urban catchments demands an explicit understanding of the catchment both spatially and temporally. This includes "identification" of critical source areas for pollutant load reduction, "prioritization" based on contaminant influence on in-stream ecological health, and "mitigation" through optimal measures. To address these three major aspects of stormwater quality management, we developed an online geospatial decision support system called "MEDUSA Online: Contaminant Loading On Demand".

This system allows catchment managers to investigate catchment characteristics, quantify loads from individual surfaces, compute in-stream concentrations in the receiving waters, prioritize sub-catchments, and simulate mitigation measures to determine impact of green infrastructure on loading and concentration. The system generates predictions of single-rain-event contaminant loads at the point of runoff from individual surfaces. The system allows users to identify the spatial distribution of contaminants as well as the relative contribution from the different surface types in the catchment at both event and annual timeframes. The system facilitates the user to explore the effects of implementing different treatment systems (surface as well as end-of-the-pipe) at any site in the catchment.

This system integrates University of Canterbury's MEDUSA (Modelled Estimates of Discharges for Urban Stormwater Assessment) engine with MIKE Powered by DHI software. MEDUSA is an event-based contaminant load model that estimates the amount of contaminants generated by individual surfaces within the catchment. MIKE suite of software is used to model hydrological, hydrodynamic and water quality processes in the stormwater network as well as in the receiving environment. The integrated system enables the identification and prioritization of critical source areas for pollutant reduction and facilitates mitigation measures for optimal siting of LID measures in urban catchments. The web-based system is accessible to a wide range of users – including Regional Council, City Council, District Council, Consultants, Infrastructure developers, and Property owners.

KEYWORDS

Water Quality; Urban Catchment; Identification; Prioritization; Mitigation; Cloud-based Geospatial Decision support system.

PRESENTER PROFILE

Dr Kalyan Chakravarthy is the Principal Water Quality Scientist in DHI Water & Environment. He has more than 10 years of industry and research experience working on various aspects of water quality management, water quality modelling, and contaminant load fate and transport in the catchments. He provides training on water quality monitoring, modeling, and management. He can be reached at cmka@dhigroup.com.

1 INTRODUCTION

In New Zealand, stormwater runoff from urban catchments mixes into a number of receiving water bodies, which range from tiny streams, rivers, and wetlands to estuaries and exposed ocean coastlines. As urban runoff contains significant levels of suspended solids, heavy metals, and other contaminants, the receiving aquatic ecosystem undergoes acute and chronic adverse effects.

The quality of stormwater reaching the receiving waters can be improved through both pollutant source reduction measures and treatment measures. For established urban catchments, where retrofitting effective stormwater treatment can be impractical, source control is the key to minimizing on-going impacts of polluted stormwater. It also has greater potential for sustainable reductions in contaminant loads than conventional treatment methods, which can slow down but cannot halt build-up of contaminants in the receiving environments.

Research in urban stormwater quality management has shown that runoff from impermeable roof, road and carpark surfaces are key contributors of contaminants to waterways (Charters et al. 2016). Pollutant build-up and wash-off differs across impermeable surface types, as these processes are influenced by factors such as surface material type, condition, and age, as well as by rainfall characteristics such as intensity, pH, number of antecedent dry days, and event duration.

Therefore, characterization of the catchment and the untreated runoff quality both spatially and temporally is necessary to guide the selection of effective and efficient stormwater management options that can reduce the water quality impact in receiving bodies. Such characterization can then be used to develop predictive models for estimating the pollutant load being generated from each surface under a range of rainfall conditions. These models can assist with the development of targeted stormwater management strategies. However, current stormwater quality models typically are either annual load models that use unit area pollutant load factors (Golder Associates 2014) or aggregate the contributing surface areas by land use (Council 2010). Such models neither identify the peak concentrations responsible for acute toxicity effects nor enable targeting of 'hotspot' surfaces to assist with selecting appropriate management options as per surface characteristics (Charters et al. 2014).

To overcome the limitations in currently available models and systems, we developed a GIS based decision support system that performs –

- "**Identification**" of critical source areas for pollutant load reduction;
- "**Prioritization**" based on contaminant influence on in-stream ecological health;
- "**Mitigation**" through best practice stormwater management systems.

This system is called “MEDUSA Online: Contaminant Loading On Demand”. It is built as an online web portal for ease of user interactivity - anytime and anywhere. This system integrates University of Canterbury’s MEDUSA (Modelled Estimates of Discharges for Urban Stormwater Assessment) engine (Fraga et al. 2016) with MIKE Powered by DHI software (DHI 2004). MEDUSA is an event-based contaminant load model that estimates the amount of contaminants generated by individual surfaces within the catchment. MIKE suite of software is used to model hydrological, hydrodynamic and water quality processes in the stormwater network as well as in the receiving environment.

In this paper, we present the application of the system on Addington Brook catchment in Christchurch. Addington Brook is a stormwater-influenced brook that headwaters near Blenheim Road, west of Matipo Street, in western Christchurch and joins the Avon River/Ōtākaro near the Christchurch Hospital. Instream surface water quality monitoring has shown elevated heavy metal concentrations in the brook near its confluence with the Avon River/Ōtākaro and it is thought to be a major contributor of the contaminants into the Avon River/Ōtākaro system and downstream estuary. Stormwater runoff from impervious surfaces in the catchment, such as roofs, roads and carparks, is one of the key sources of heavy metals and sediment into the brook. There is limited treatment of the runoff prior to it entering the brook. The application of the system on Addington Brook catchment was done in close collaboration with Environment Canterbury. Total Suspended Solids (TSS), Zinc, and Copper were selected as the contaminants of interest in this catchment.

2 THREE STEP PROCESS

2.1 IDENTIFICATION

Figure 1: Query catchment characteristics

The first step in stormwater quality management is to characterize the catchment. In the system, this is presented in two modes – Setup and Results. In both modes, the system resolves the catchments into individual surfaces – roofs, roads, carparks, pervious areas, and Green Infrastructure. The locations in-stream where the stormwater network enters the waterway are highlighted as Discharge Points. Based on the catchment shape file inputs to the system, each surface is characterized by its attributes such as area, material, and address. Thus, the system provides catchment characterization at a high spatial resolution.

As shown in Figure 1, the user can query the attributes by clicking on any surface. In Results mode, user can query the amount of contaminant load generation at any surface as well as at event level. Results are generated for three typical rainfall years – dry, average, and wet, classified according to the annual cumulative rainfall. User can query either the annual average load generation value or event specific value from the event distribution graph, as shown in the bottom right corner of Figure 2. Sub-catchment aggregated load results can also be queried at each Discharge Point. Event mean in-stream concentration values for Addington Brook are generated at each Discharge Point, using the event loads from contributing surfaces in the sub-catchment and flow routing.

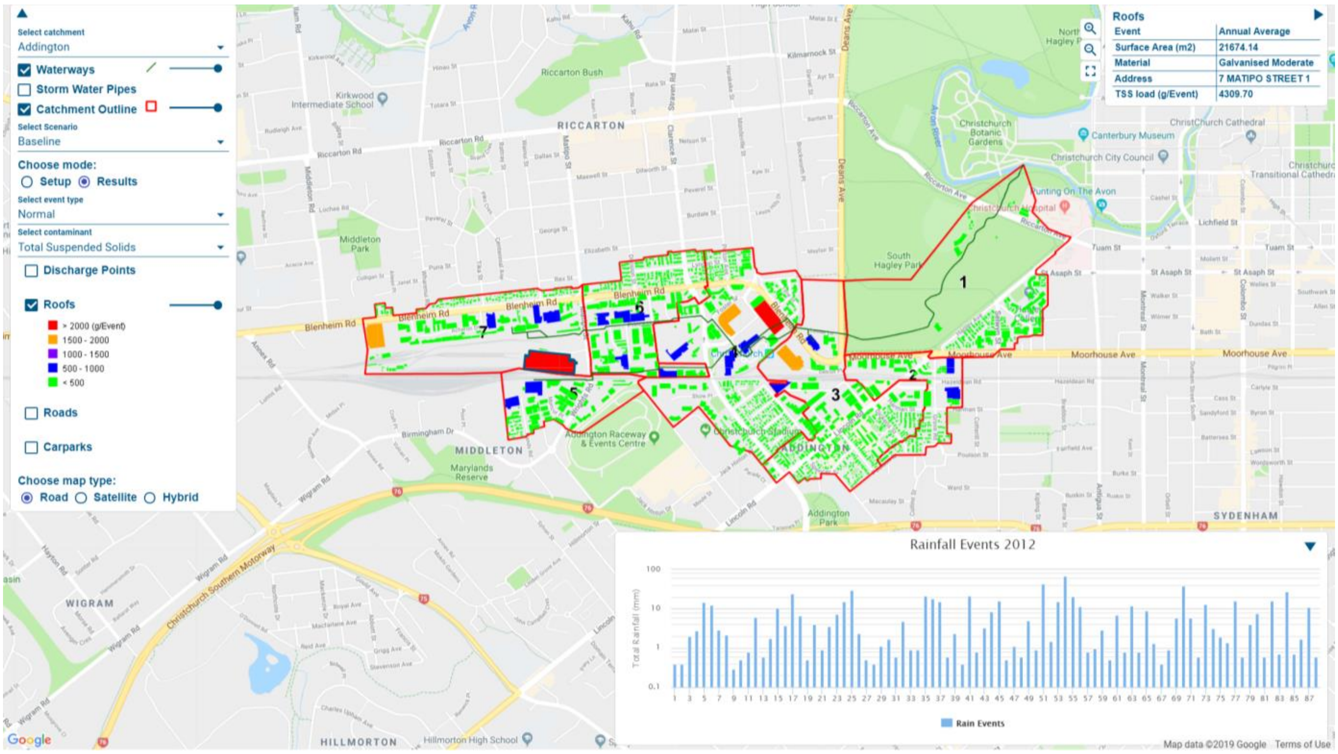

Figure 2: Query surface specific loads

2.2 PRIORITIZATION

The second step in stormwater quality management is to prioritize the sub-catchments in the order of load reduction to improve water quality in the receiving environment. This is achieved in the system by determining the load distribution at sub-catchment scale. Figure 3 shows the loads distribution in the catchment at holistic level in baseline stage. Each surface is color coded (blue, green, purple, orange, and red) to showcase loads at different ranges. At catchment level, the user can identify that Sub-Catchments 4 and 7 show higher proportion of loads as compared to the rest. Figure 4 shows the summary of loads aggregated at each sub-catchment. Sub-Catchments 4 and 7 contribute 25.1% and 23.6% of the TSS loads generated per event on an annual average in the catchment. The baseline results indicate that Sub-Catchments 4 and 7 should be prioritized over others for mitigation of TSS loads.

Since the system discretizes the annual precipitation to storm events, it identifies the frequency of threshold breaches of the in-stream concentration in a given year. In the average rainfall year, the in-stream TSS concentration at Discharge Point 1, where the Addington Brook mixes into the Avon River/Ōtākaro, exceeds the threshold about 40% of the time although the annual average value is below the threshold guideline value.

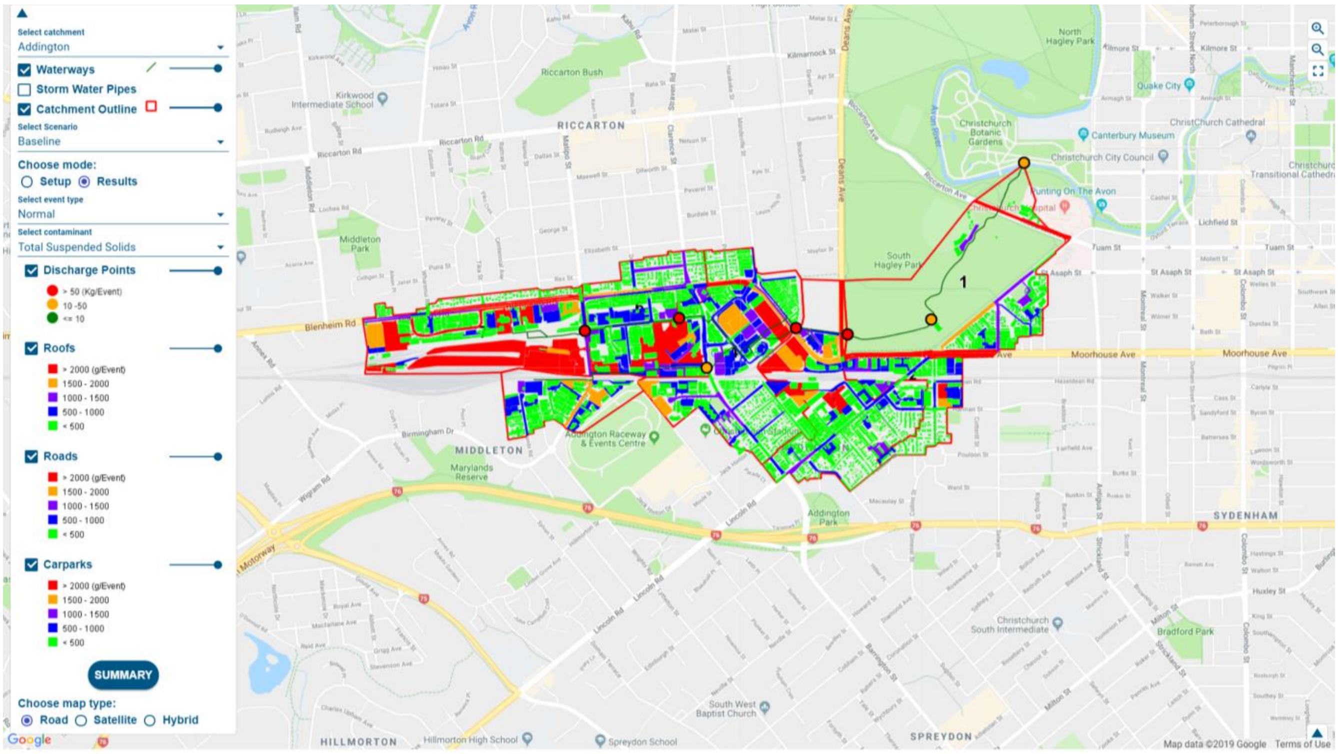

Figure 3: Pollutant load generation across the sub-catchments

Figure 4: Load generation summary for all the sub-catchments

2.3 MITIGATION

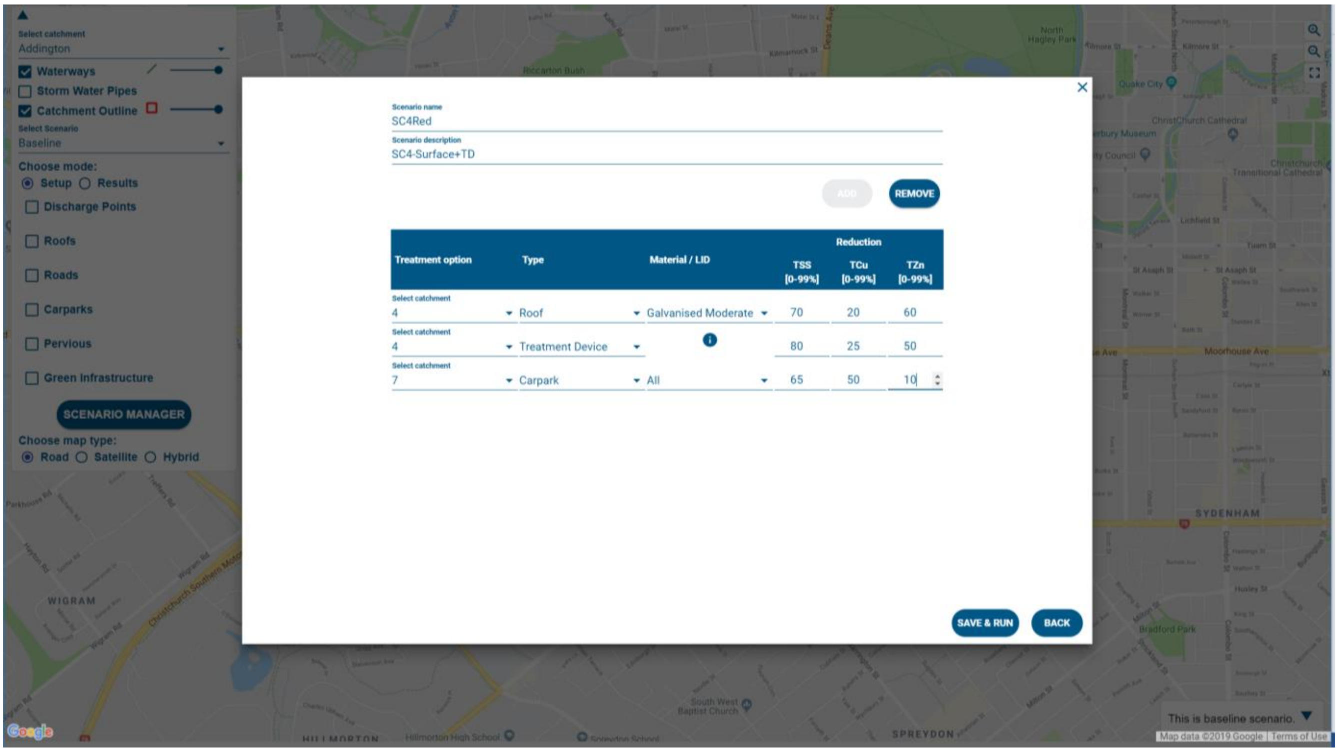

Figure 5: Scenario Generation – Load Reduction through source control and Treatment Devices

The third step in stormwater quality management is to have the option to develop several mitigation scenarios to select which option provides the best solution in terms of load reduction and water quality improvement. The system has a dedicated scenario generation option as shown in Figure 5. The user has three options per scenario to choose either surface level treatment (source control) or a treatment device. In the scenario shown, mitigation is applied by treating Galvanized roof runoff and providing treatment (e.g. a wet pond) of combined runoff prior to discharge in Sub-Catchment 4, while all carpark surface runoff is treated in Sub-Catchment 7. This scenario captures both source control and end of the pipe treatment options to reduce contaminant load reaching the receiving environment.

To assist the user in choosing appropriate load reduction from the treatment device, a table of removal efficiencies of different contaminants is provided for quick reference. Table 1 shows a summary of removal efficiencies derived from paired sampling data of various devices found in the International Best Management Database. This table contains a large data set of monitored grass strips, bioretention, bioswales, composite/treatment train BMPs, detention basins (surface/grass-lined), media filters (mostly sand filters), porous pavement, retention ponds (surface pond with a permanent pool), wetland basins (basins with open water surface), a combined category including both retention ponds and wetland basins, and wetland channels (swales and channels with wetland vegetation). The effectiveness and range of unit treatment processes present in a particular BMP category may vary depending on the BMP design.

It is important to note that contaminant removal efficiencies can vary greatly between stormwater treatment systems and as a function of a range of factors such as:

- Suitability of the treatment type to expected contaminants;
- Adequacy of sizing and construction;
- The size of the storm and the amount of stormwater bypassing;
- Adequacy of maintenance;
- Influent stormwater quality (concentrations, volumes, form – particular/dissolved);
- Stormwater pH, temperature, and other environmental factors.

It is thus recommended that conservative average values of removal rates be used in the modelling (removal rates can also vary on an event by event basis.) and that extensive sensitivity analyses be conducted for critical installations. If proprietary or commercial stormwater treatment devices are used in the modelling, we recommend examining the recommended treatment efficiencies and adjusting values for local conditions.

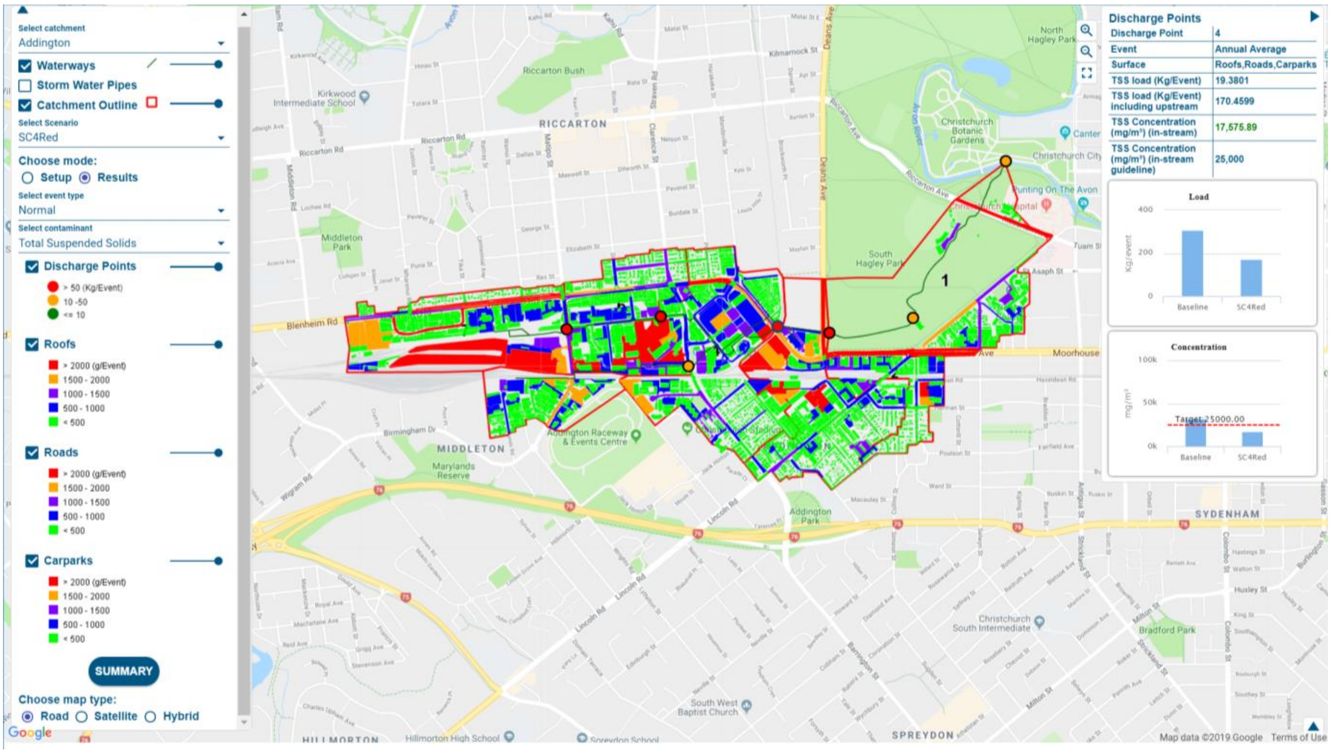

Figure 6: Mitigation Scenario - Load reduction at Sub-Catchments 4 and 7

Results of the selected mitigation scenario show that source control and treatment device application has improved the in-stream concentration of TSS at Discharge Point 4 by 45%. As compared to the baseline scenario in which the TSS in-stream concentration exceeded the threshold guideline value, in the mitigation scenario, the load reduction resulted in lower in-stream concentration. As reduction was also applied in the form of source control in Sub-Catchment 7, 43% TSS load reduction was observed at Discharge Point 7 in the mitigation scenario as compared to the baseline scenario. At Discharge Point 1, where Addington Brook mixes into the Avon River/Ōtākaro, water quality improvement is observed to be 31% for TSS, 17% for Zinc, and 16% for Copper respectively.

Table 1: Contaminant removal efficiency ranges derived from paired sampling data (Source - International Best Management Database - http://www.bmpdatabase.org/)

Treatment System[a]	TSS removal efficiencies			
	Sample Count	25^{th} Percentile[b]	50^{th} (median)	75^{th}
Bioretention	476	30%	75%	92%
Composite [c]	187	47%	76%	93%
Detention Basin	429	16%	58%	76%
Grass Strip	590	-17%	50%	77%
Grass Swale	386	-39%	24%	60%
Infiltration Basin	16	-3%	64%	91%
Manufactured Device [d]	1246	11%	47%	76%
Media Filter	415	60%	80%	92%
Other	63	7%	34%	53%
Porous Pavement	162	-16%	53%	83%
Retention Pond	787	35%	75%	91%
Wetland Basin	415	15%	57%	79%
Wetland Basin/Retention Pond	1202	24%	68%	88%
Wetland Channel	224	-25%	33%	68%
Notes:	[a] This data is derived from paired sampling of a wide range of devices submitted to the International BMP database and should only be used to get a general indication of efficiencies. Factors such as media type, soils types, hydraulic properties, maintenance, and various other properties result in the wide distribution of efficiencies between the 25^{th} and 75^{th} percentile range. [b] Negative values indicate potential contribution of contaminants from the treatment system (usually at the 25 percentile range of samples). In some samples, low inflow and outflow concentration values may have resulted in negative values due to errors in detection range. [c] Composite refers to a treatment approach using 2 or more systems (i.e. grass swale + bioretention). [d] Manufactured devices include a wide range of commercial systems and thus only give a general overview of performance.			

3 CONCLUSIONS

A web-based stormwater quality management system is discussed in this paper. This system is accessible to a wide range of users – including councils, consultants and property owners – who would benefit from guidance in identifying contaminant hotspots as well as in the selection of appropriate source reduction and treatment options in the catchment. The benefits offered by the system are summarized below –

- Determines event-based pollutant loads (temporal resolution of hours, not years).
- Peak contaminant loadings quantified for every surface, event, and discharge point (providing the highest level of spatial resolution).
- Aggregates individual surface and event results to be aggregated over time (seasonal or yearly) and space (sub-catchments, catchments, or regions) to support design of solutions from site scale to strategic planning scale.
- Integrates local climatic conditions into the contaminant load calculations.
- Combines pollutant at-source model with flow routing models (MIKE 11/URBAN).
- Relates catchment loads to in-stream concentrations.
- Informs the loading criteria to be used in the design of green infrastructure solutions.
- Applicable to any catchment with information on surface types and rainfall characteristics (these are the only inputs to the system).

This system lets the user easily query the catchment load and in-stream concentration results and get immediate answers with just a few clicks on a tablet, smartphone, laptop or desktop. The user can run several "what-if" scenarios in a fraction of time. As it is web-based, the system does not require the user to install or maintain any special software on their computer/tablet. As it is minimal input driven, it can be quickly customized for any urban catchment in New Zealand.

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